

# **Appendix A**

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## ***Glossary***

## A-1 LIST OF ACRONYMS AND ABBREVIATIONS

|       |  |        |   |
|-------|--|--------|---|
| 1-D   | one-dimensional                              | NMR    | nuclear magnetic resonance                  |
| 2-D   | two dimensional                              | NP     | nondeterministic polynomial (time)          |
| 2-DEG | two-dimensional electron gas                 | NV     | nitrogen-vacancy                            |
| 3-D   | three dimensional                            | P      | polynomial (time)                           |
| BEC   | Bose-Einstein condensate                     | PSPACE | problem solvable with polynomial memory     |
| BQNP  | bounded quantum analogue of NP               | QC     | quantum computing / computation             |
| BQP   | bounded quantum polynomial                   | QCPR   | Quantum Computing Program Review            |
| C-NOT | controlled-NOT (gate)                        | QD     | quantum dot                                 |
| CPB   | Cooper pair box                              | QED    | quantum electrodynamics                     |
| CV    | carbon vacancy                               | QFT    | quantum Fourier transform                   |
| CW    | continuous wave                              | QIP    | quantum information processing              |
| dc    | direct current                               | QIS    | quantum information science                 |
| DFS   | decoherence-free subspace                    | QIST   | quantum information science and technology  |
| ESR   | electron-spin resonance                      | qNOT   | quantum-NOT (gate)                          |
| FET   | field-effect transistors                     | QSAT   | quantum analog of satisfiable problem       |
| FQHE  | fractional quantum Hall effect               | rf     | radio frequency                             |
| GHz   | gigahertz                                    | SAW    | surface-acoustic wave                       |
| GHZ   | Greenberger, Horne, and Zeilinger            | SET    | single-electron tunneling                   |
| HOM   | Hong, Ou, and Mandel                         | SFQ    | single flux quantum                         |
| Hz    | hertz  | SHB    | spectral hole burning                       |
| IP    | interaction proof                            | SPD    | single-photon detector                      |
| kHz   | kilohertz                                    | SPDC   | spontaneous parametric down conversion      |
| KLM   | Knill, Laflamme, and Milburn                 | SPS    | single-photon source                        |
| LOCC  | local operations and classical communication | SQUID  | superconducting quantum interference device |
| LOQC  | linear-optics quantum computing              | STM    | scanning-tunneling microscopy               |
| MA    | Merlin-Arthur (problems)                     | T      | Tesla                                       |
| MEMS  | micro-electro-mechanical systems             | TEP    | Technology Experts Panel                    |
| MHz   | megahertz                                    | UV     | ultraviolet                                 |
| mK    | millikelvin                                  |        |   |
| MRFM  | magnetic resonance force microscopy          |        |   |

## A-2 GLOSSARY OF TERMS

**Bell inequalities** – A set of constraints that certain measurement results must satisfy if the underlying theory is local and realistic; quantum mechanics predicts results that violate these inequalities, thereby disproving local realism.

**Bell measurement** – A joint measurement on two quantum systems to determine which of the 4 Bell states they are in; to make a completely unambiguous Bell measurement usually requires a strong nonlinear interaction between the systems.

**Bell states** – For a quantum state with two subsystems (*i.e.*, two qubits), the 4 orthogonal maximally entangled states (*e.g.*,  $|100\rangle\pm|111\rangle$ ,  $|100\rangle\mp|110\rangle$ ,  $|101\rangle\pm|100\rangle$  and  $|101\rangle\mp|101\rangle$ ).

**Bose-Einstein condensate** – A state of a tenuous, very low-temperature gas in which all the atoms occupy the same motional quantum state; typically all the atoms are essentially at rest.

**Cat state** – a simultaneous superposition of two different states, usually macroscopic. (This state is classically forbidden.)

**cavity quantum electrodynamics** – Individual atoms interacting with the strong electromagnetic field inside a small optical-frequency cavity.

**coherent control** – control which maintains quantum coherence.

**computational basis** – a set of quantum basis states upon which a computation is done.

**correlation** – Cosine of the angle between two states.

**decoherence** – normal loss of quantum coherence (both inherent and due to interactions with the environment).

**discriminating single-photon detector** – A photon counter that detects one or more photons with high efficiency and can robustly discriminate between 0, 1, 2, or more photons.

**entanglement** – The property of two or more quantum systems whose total quantum state cannot be written as a product of the states of the individual systems (*c.f.*, separable state); this property introduces nonlocality into quantum theory, and is believed to be an essential ingredient of quantum information processing.

**exchange coupling** – Basic physical interaction between the spins of electrons whose wave functions overlap, arising from the Pauli exclusion principle.

**fault-tolerant quantum computation** – a quantum computation that can proceed accurately in spite of errors.

**fidelity** – The magnitude of the projection of one state on another.

**GHZ (Greenberger, Horne, and Zeilinger) and W states** – There are two classes of entangled states for a three-qubit system in the sense that a state in one class cannot be transformed into a state in the other class by local operations and classical communication (LOCC). There are two orthogonal GHZ states (with the form  $|100\rangle\pm|111\rangle$ ) and six orthogonal W states (with the form  $|101\rangle\pm|110\rangle\pm|100\rangle$ ). The GHZ states are pure states specified by the correlation “all qubits have the same value.” The W states are specified by the correlation “any two qubits are correlated.”

**holonomic constraint** – a type of constraint on a system of particles, expressible in the form,  $f(x_1, x_2, x_3, \dots, x_N, t) \equiv 0$ .

**HOM interferometer** – A quantum interferometer, first implemented by Hong, Ou, and Mandel, in which single photons enter each of the two input ports of a 50:50 beam splitter. The

probability for coincidence counts at the two output ports is zero when temporal and spatial mode-matching is perfect. This is the required test of a single photon source intended for linear-optics quantum computing. Also, the HOM interferometer is useful for polarization Bell-state analysis, as required (e.g., in quantum dense coding and teleportation).

**linear optics** – Any optical device that is described by a Hamiltonian which is at most quadratic in the field amplitudes. Such devices include phase-shift components, mirrors, beam splitters, and polarizers. The class may be extended to include devices that make use of the second-order susceptibility in which one of the fields is classical (e.g., parametric down conversion with a classical pump field). As the Hamiltonian for a linear optical device is, at most, quadratic in the field amplitudes, the resulting Heisenberg equations of motion are linear in the field amplitudes.

**logical qubit** – A combination of physical qubits that is more robust against a specific set of noise generators.

**magnetic microtrap** – A configuration of magnetic fields in which atoms can be trapped in the regions of strongest field strength via the interaction of the atomic magnetic-dipole moments with the magnetic field.

**optical dipole force** – When an atom is exposed to light, the electric field of the light induces an optical-frequency electric-dipole moment in the atom, and then the electric field exerts a DC optical dipole force on the induced dipole.

**optical lattice** – A pattern of standing light waves created by the interference of intersecting laser beams; neutral atoms can be trapped in the standing-wave pattern by optical dipole forces.

**optical microtrap** – A configuration of tightly focused light beams; atoms can be trapped by optical dipole forces in the regions of greatest light intensity.

**physical qubit** – A system that has observables that behave as the Pauli matrices.

**quantum dot** – A confining structure for electrons, which can be designed to stably hold a small number of electrons.

**quantum error correcting code** – a set of quantum operations which tests for errors and corrects errors that are found.

**quantum jump detection** – experimental detection of a discrete change in a quantum state.

**quantum logic operation** – a quantum operation which performs reversible logic (NOT, C-NOT, etc.).

**quantum measurement** – an experimental procedure for determining some or all of the parameters that specify a quantum state.

**quantum parallelism** – utilization of quantum superposition to do many operations simultaneously.

**quantum state and quantum process tomography** – In quantum state tomography, a number of measurements are made on an ensemble of identically prepared quantum systems. If the Hilbert space is of finite dimension, then a finite number of measurements suffices to allow one to reconstruct the quantum state of the particles. Quantum process tomography uses similar techniques to characterize a quantum process (e.g., a unitary transformation, decoherence, etc.). This means the effect on any possible input state to the process may be predicted.

**qubit** – an abbreviation for “quantum bit”, the basic computation building block of most quantum computer paradigms. In addition to being able to assume the values “0” and “1”, a qubit can also be put into a quantum superposition of 0 and 1 at the same time (e.g.,  $|0\rangle + |1\rangle$ ).

**Rabi oscillation** – a two-state system driven by an electromagnetic wave whose energy equals the energy difference between the two states. (This driven system oscillates periodically between the two states.)

**reversible computation** – a computation for which the time-reversed sequence can also be realized; (no dissipation occurs)

**Rydberg atom** – An atom with one valence electron that has been excited to a high-lying (Rydberg) energy level.

**scalability** – the capability of achieving the same efficiency, almost independent of the number of qubits.

**separable state** – The description of two or more quantum systems which are not entangled, so that it is possible to write the total state of the joint system as a product of the quantum state of each individual piece

**single-photon source** – A transform-limited pulsed optical field with one and only one photon per pulse. The pulses must exhibit first-order coherence (i.e., must exhibit self interference) and must enable two-photon interference (e.g., Hong, Ou, and Mandel interferometer) using a delay line.

**spontaneous parametric down conversion** – The current method of choice for producing pairs of correlated photons. A high-frequency photon is split into two lower-frequency daughter photons via a nonlinear optical crystal. In addition to being able to directly create polarization-entangled pairs, several groups are pursuing it as a means to realizing a single-photon source.

**superoperator** – general class of quantum operator corresponding to the dynamics of open quantum systems.

**superposition** – a linear combination of two or more quantum states

**teleportation** – a quantum communication protocol, whereby an unknown quantum state can be indirectly transmitted from one party to another; the protocol requires sending four classical bits of information, and that the parties share entanglement

**Toffoli gate** – operator acting on three two-state qubits. Only when the first two qubits are in the down state, does the Toffoli gate flip the third state.

## **Appendix B**

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## B-1 LIST OF REFERENCES FOR THE QUANTUM COMPUTING ROADMAP

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